Army Research Laboratory

Hybrid Log Spiral with Loop Antenna

by Neal Tesny and Marc Litz

ARL-TR-5106 March 2010

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14. ABSTRACT

We fabricated a hybrid antenna that consists of a logarithmic spiral and loop antenna. The antenna was designed to detect electromagnetic (EM) noise and be broadband in the range of 1 MHz to 1 GHz. This style of antenna can be located in buildings and passageways in inaccessible areas for the purpose of shielding integrity surveillance and life cycle shielding degradation monitoring, and can be used as permanent fixtures that detect critical threshold levels of unwanted EM radiation. The antenna structures were modeled with the FEKO EM numerical code and were also experimentally characterized in the laboratory. The measurements compare well with the predictions from the modeling. This report presents the detailed results of the design, and the FEKO analysis and the measured results.

15. SUBJECT TERMS

Hybrid antenna, spiral antenna, loop antenna, wideband

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1. Objective

Shielding integrity surveillance and life cycle shielding degradation monitoring are often performed in buildings and passageways which are inaccessible with the large antennas needed for coverage of the appropriate bandwidths. Hence, we desired to develop a thin, wideband antenna for use in confined, narrow spaces for the use of wideband measurements. Our desire was to have an antenna with a frequency range of interest of 10 kHz to 1 GHz and with an unpolarized response.

The logarithmic spiral antenna, first described by Dyson in 1959, would be specified entirely by angles. The performance would then be independent of wavelength, with the limit of the lowest frequency transmitted being dependent on the length of the spiral arms. Antennas of this sort were constructed with bandwidths of over 20:1 (*1*).

Curtis found that for an Archimedean spiral, the high-frequency limit is determined by the feed configuration, and that the low-frequency limit occurs when the outside diameter is a little greater than a half wavelength (*2*).

2. Approach

The approach was to design a hybrid antenna that would consist of two antenna portions. The two portions would be 1) a printed logarithmic spiral to cover the upper range of frequencies from 20 MHz to 1 GHz, and 2) a square loop to cover the lower range of frequencies from 10 kHz to 20 MHz.

A log spiral antenna was designed by Polun (*3*) and manufactured at the U.S. Army Research Laboratory (ARL).

Models of the antenna were then fabricated at ARL. We modeled the antenna using FEKO modeling software (*4*). We then performed anechoic chamber tests to characterize the fabricated antenna.

3. Design Goals

The design goals of the loop antenna portion include the following:

- Frequency Range: 10 kHz–20 MHz

- Flat low-profile footprint
- 1.5 Decade Bandwidth or Greater
- Gain >3 dBi
- Impedance match to ~50 Ω

The design goals of the log spiral antenna portion include the following:

- Frequency Range: 10 MHz to >1.0 GHz
- Physically flat, low-profile footprint
- 1.5 Decade Bandwidth or Greater
- Gain >3 dBi
- Impedance match to ~50 Ω

In addition to the above performance requirements, the antenna would be versatile in the following ways:

- Inexpensive
- High power levels (100 W) as sensor
- CW and Pulse Applications
- Use in confined spaces
- Provides Circular Polarization

Its applications would include the measurement of electromagnetic (EM) Shielding Effectiveness in confined spaces and as facility-embedded EM sensors for receive antennas, as in the environment shown in figure 1.

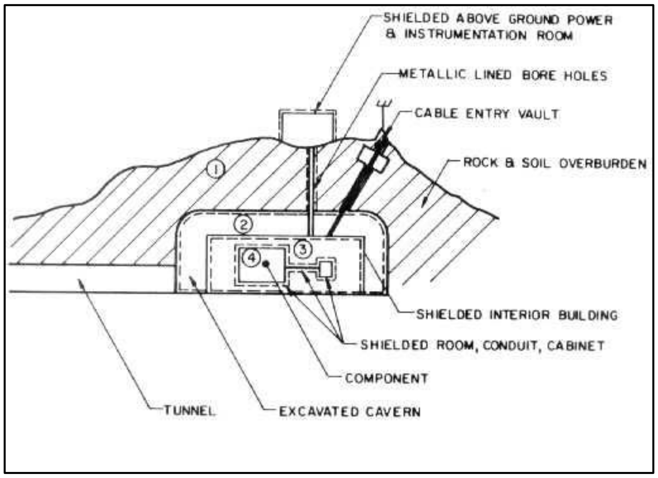

Figure 1. A use for the low profile hybrid antenna.

4. Log Spiral Fabrication

The log spiral portion was CAD-designed, and Gerber files were generated for the fabrication process using a circuit board. It was fabricated in-house at ARL. The dimensions of the fabricated log spiral antenna are 97 x 76 cm (38 x 30 in).

The equations, in polar coordinates, are (*3*)

Inner right spiral: $r = 0.5e^{0.1103\cdot\theta}$

Outer right spiral: $r = 0.5e^{0.1103\cdot\theta+0.1823}$

Inner left spiral: $r = -0.5e^{0.1103\cdot\theta}$

Outer left spiral: $r = -0.5e^{0.1103\cdot\theta+0.1823}$

where

r is radius,

θ is polar angle, in radians.

The modeled and fabricated log spiral antennas are shown in figures 2 and 3.

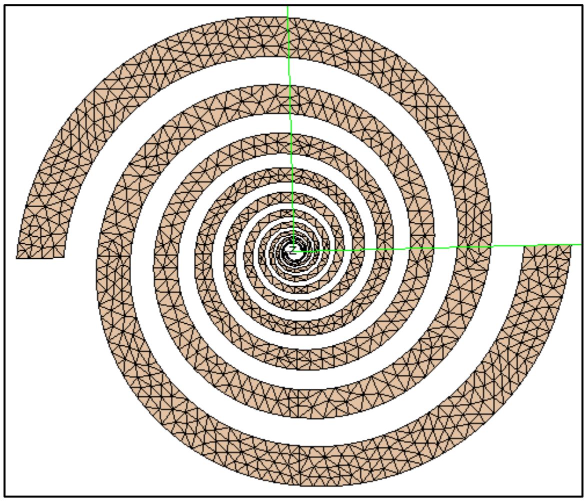

Figure 2. Modeled log spiral antenna, with approximately 4000 method of moment elements.

Figure 3. Fabricated log spiral antenna.

5. Log Spiral Results

5.1 Modeled

The modeled gain for an ideal, matched source and a 50 Ω source are shown in figure 4. The ideal source showed a peak gain of approximately 6 dBi at 473 MHz. The gain levels off at around 2 dB below 50 MHz.

For the 50 Ω source, the peak gain was approximately 2 dBi and was relatively flat at frequencies over 100 MHz. The gain drops off significantly below 100 MHz.

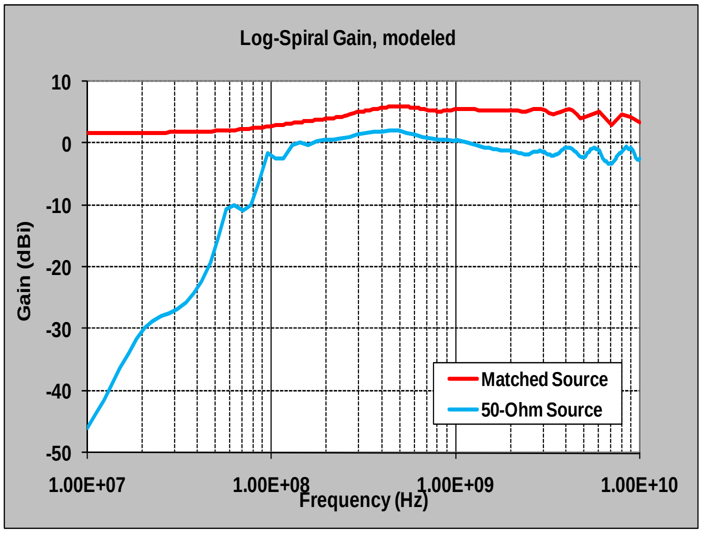

Figure 4. Modeled antenna gain for ideal and 50 Ω source.

The modeled input impedance is shown in figure 5. In the100 MHz–1 GHz region of interest for the spiral, the input impedance was shown to be 200–300 Ω.

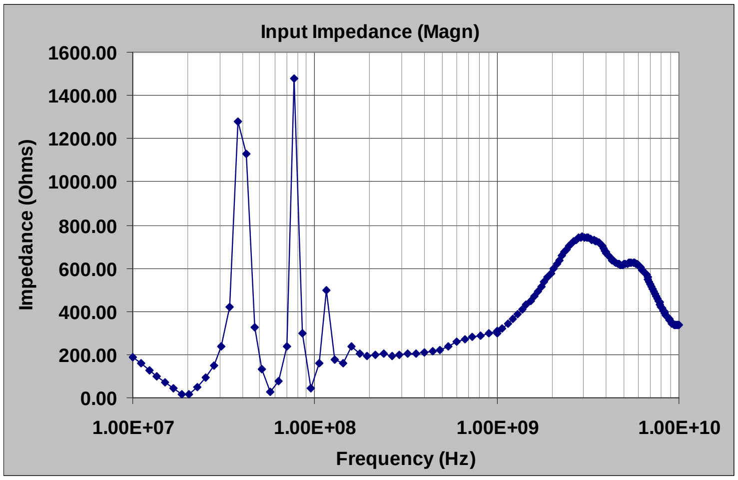

Figure 5. Modeled input impedance magnitude.

The modeled input impedance for the resistive and reactive components (known as real and imaginary in mathematics) is shown in figure 6. Above 100 MHz, the reactive response is primarily greater than 0, which indicates inductive reactance in the 100 MHz–1 GHz region of interest. The resistive component dominates above 80 MHz.

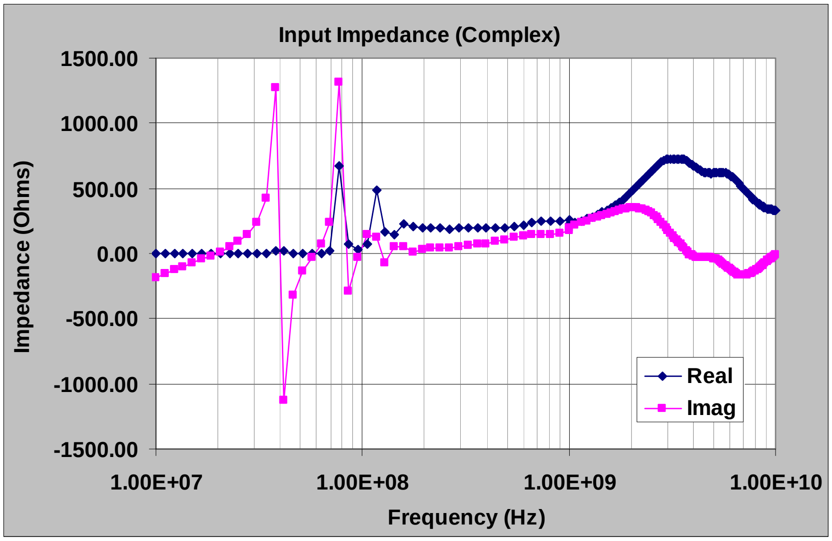

Figure 6. Modeled complex input impedance of log spiral antenna.

5.2 Measured

5.2.1 Balun

A balun was used in the measurements of the log spiral antenna. It is shown in figure 7, and its design is shown in figure 8. It is a 2:1 wideband coplanar, stripline balun mounted on the log-spiral feed. Its dimensions are 40 mm by 30 mm by 14 mm. The balun was designed to match a 100 Ω load to a 50 Ω load.

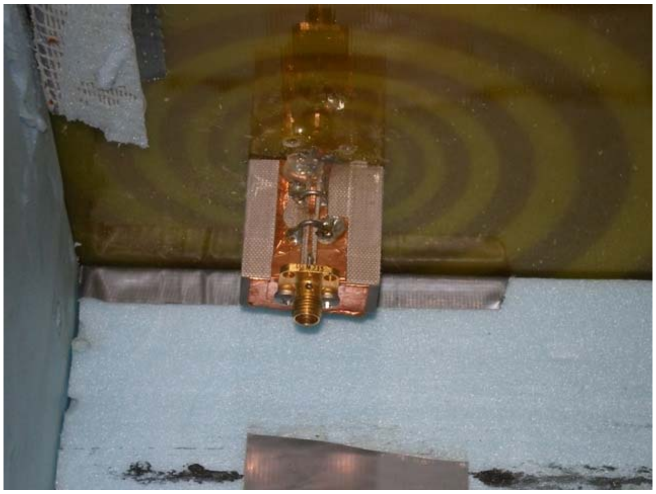

Figure 7. Balun attached to log spiral feed.

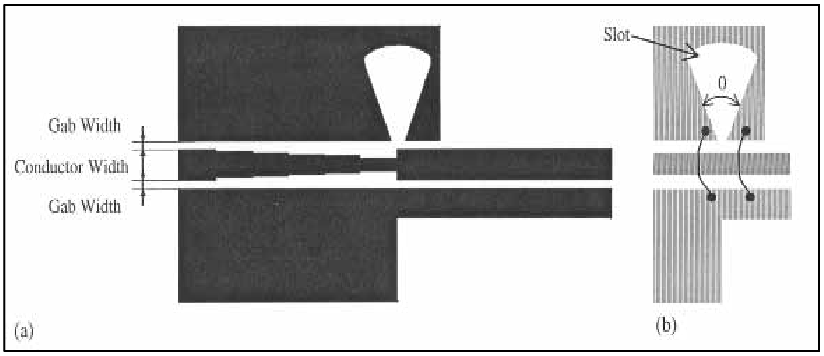

Figure 8. Design of wideband balun.

5.2.2 Experimental Test Results

The log spiral antenna gain was measured in an anechoic chamber. The results of the antenna with and without a balun are shown in figure 9. The plot illustrates that the balun provided a much smoother gain curve.

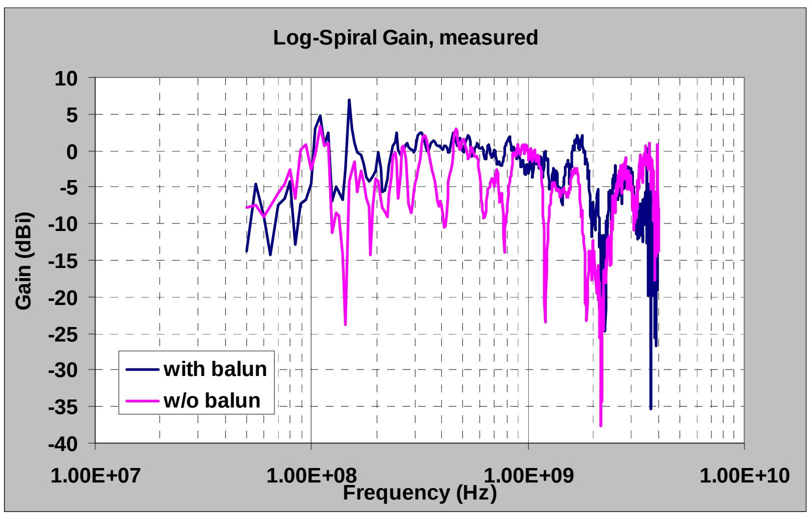

Figure 9. Measured gain of log spiral antenna, with and without balun.

The gain shown with an expanded frequency scale in main range of interest is shown in figure 10. From the plot, there is a 0–2 dBi gain in range of interest with the balun.

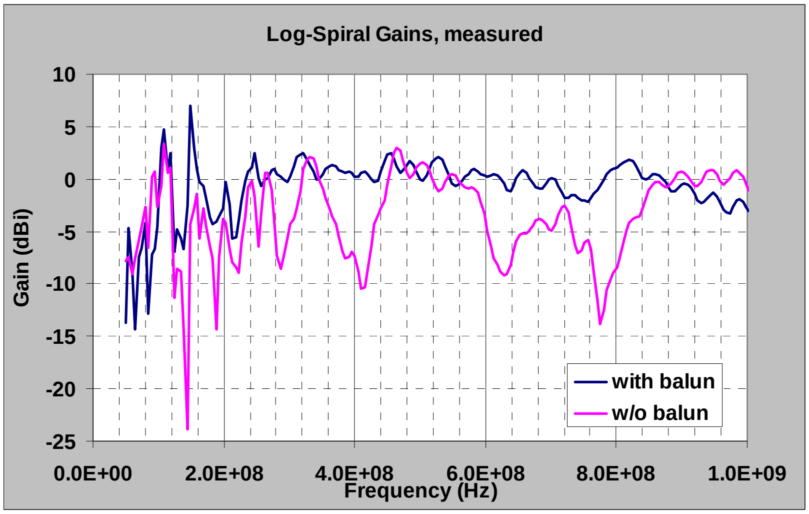

Figure 10. Measured gain of log spiral antenna, expanded linear scale.

The magnitude of the measured Input Impedance with and without the balun is shown in figure 11. In the frequency range of interest, the mean impedance without the balun was 77 Ω. However, the large ringing in this region shows large variations in impedance, while the balun provides much more stable impedance along the frequency range of interest, which is sufficient for the application.

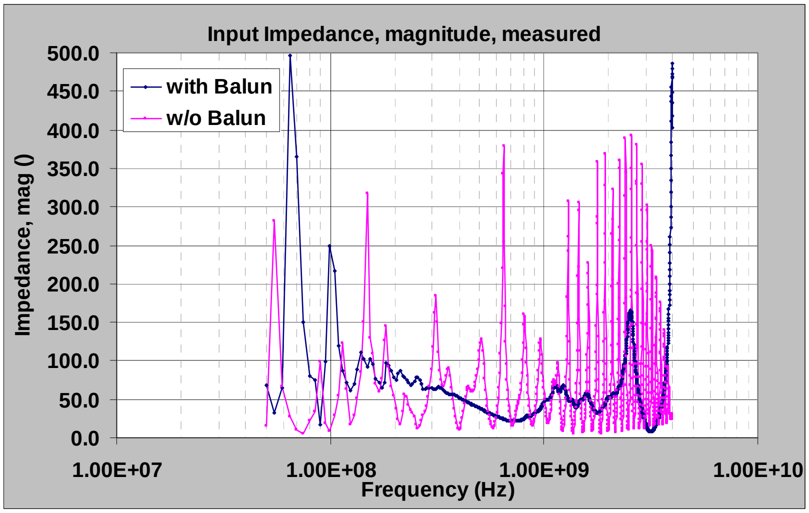

Figure 11. Input impedance of log spiral antenna, with and without balun.

This is also seen in the measurement of the reflection coefficient S11, which is shown in figure 12. The reflection coefficient is better above 100 MHz with the balun in place.

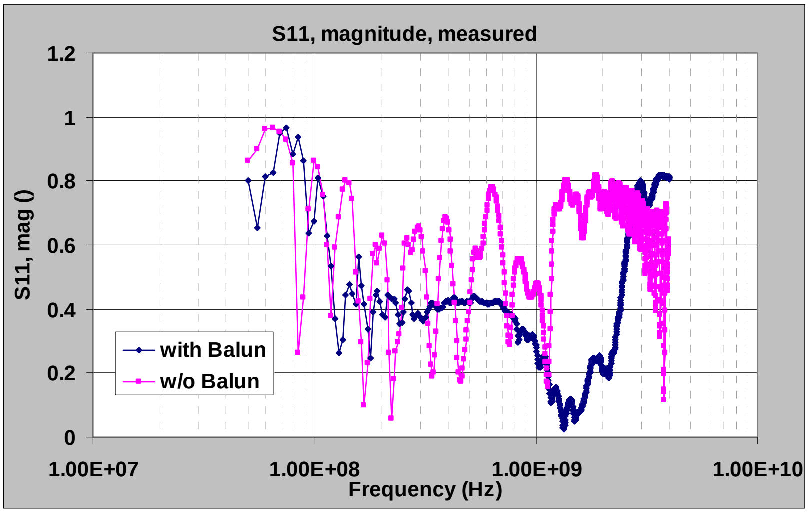

Figure 12. Reflection coefficient of log spiral antenna, with and without balun.

A comparison of the simulated and measured gain of the log spiral antenna is shown in figure 13. Table 1 shows the average gain over the frequency range of interest. This shows generally good agreement (<1 dB) between measured and simulated gain.

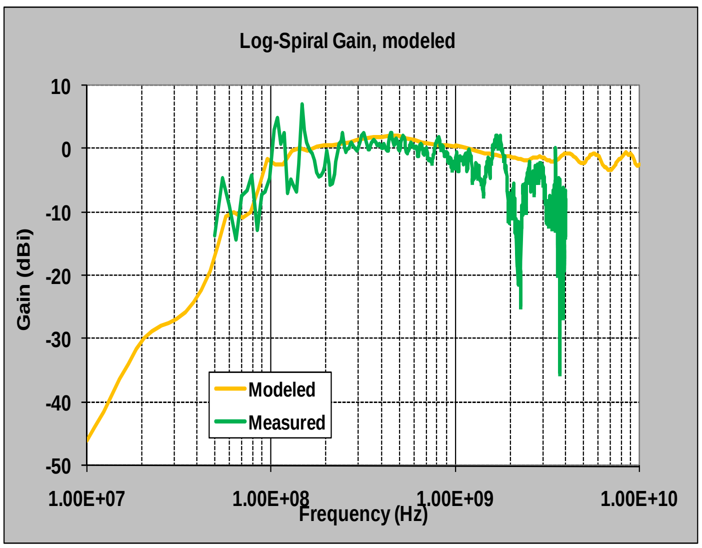

Figure 13. Simulated and measured gains of the log spiral antenna.

Table 1. Mean simulated and measured gains in frequency region of interest.

	100 MHz–1 GHz
Meas w/o Balun	–3.5
Meas with Balun	–0.2
Simulation	0.7

6. Loop Antenna Results

The log spiral antenna with the loop is shown in figure 14. The dimensions of the loop are 97 x 76 x 15 cm (38 x 30 x 6 in). It was constructed from 0.5-in copper tubing to provide durability and minimize resistance.

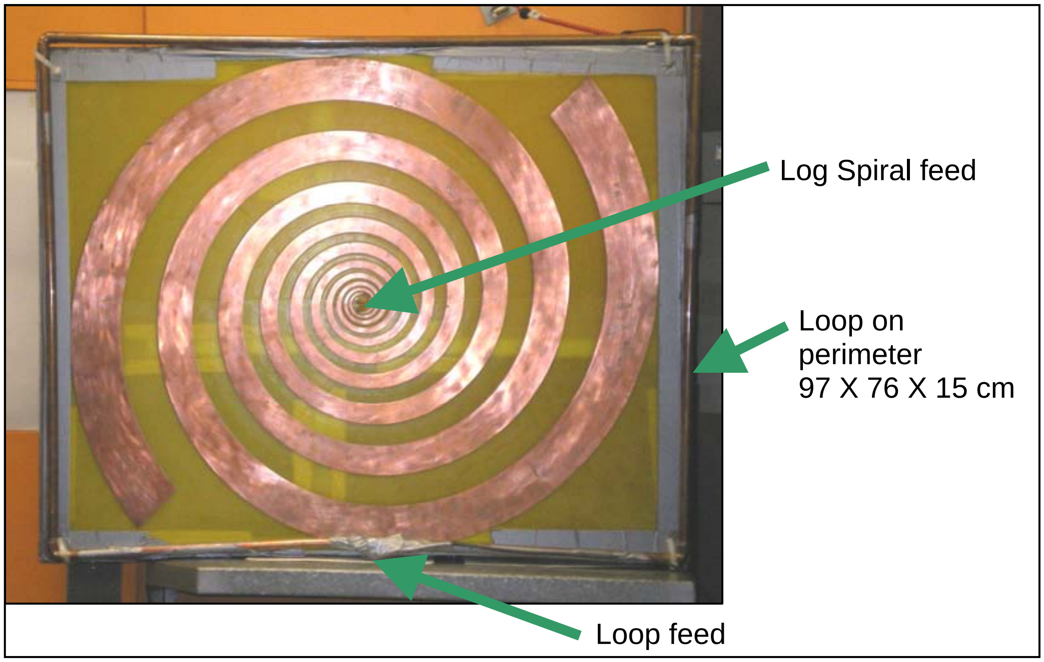

Figure 14. Hybrid log spiral with loop antenna.

The modeled and measured gains of the loop antenna are shown in figure 15. These are along the coplanar axis of the loop. The measured range was from 10 kHz to 20 MHz, and the modeled range was from 10 kHz to 1 GHz. The results show good agreement between measured and modeled loop gains.

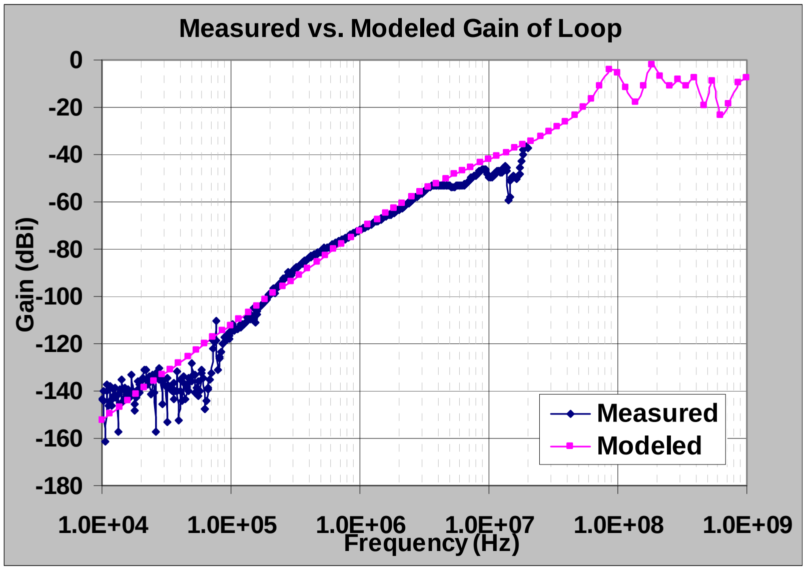

Figure 15. Modeled and measured gains of loop antenna.

7. Conclusions

A hybrid loop-spiral was designed and evaluated. The loop portion covers the frequency range of 10 kHz to 20 MHz. The spiral portion covers the frequency range of 100 MHz to 1 GHz.

The hybrid antenna has a wide bandwidth capability and is used extensively on field tests. It is lightweight and has a thin profile. The gains are approximately 0 to 2 dBi, as compared to a standard log periodic antenna of about 6 dBi.

The input impedance of the log spiral portion is roughly 100 Ω; a balun, however, corrects this to roughly 50 Ω.

In practice, the hybrid antenna provides good performance. Though, deficiencies exist from 10 kHz to 100 kHz and from ~5 MHz to ~50 MHz.

These hybrid antennas are installed in buildings and passageways, and in inaccessible areas for the purpose of shielding integrity surveillance and life cycle shielding degradation monitoring. They are useful as permanent fixtures that detect critical threshold levels of unwanted EM radiation.

7.1 Future Work

Future work includes

- Improve balun for better broadband characteristics

- Develop low-loss, cross-over network between antennas
- Fabricate a two-turn Loop for Higher Sensitivity
- Increase copper print-thickness (skin depth) on spiral to get higher gain [10 MHz to 100 MHz]

An additional method for extending the low frequency performance involves terminating the ends of the spiral arms and is described in (*5*), in which bandwidths of 100:1 are achieved. A version of this technique could also be applied to the log spiral for additional gain at low frequencies.

Thicker copper printed on the board would allow lower frequency content, according to the following equation and plotted in figure 16. For our application, the skin depth of copper at 10 MHz would be 20.6 µm. Having a rule of thumb of 5 skin depths would necessitate a board thickness of 103 µm.

$$\delta_s = \sqrt{\frac{2}{\omega * \mu * \sigma}} = \sqrt{\frac{\rho}{\pi * f * \mu}}$$

where: μ = permeability ($4\pi * 10^{-7}$ H/m), note: H = henries = Ω*s
π = pi
δ_s = skin depth (m)
ρ = resistivity (Ω*m)
ω = radian frequency = 2π*f (Hz)
σ = conductivity (mho/m), note: mho [℧] = siemen [S]

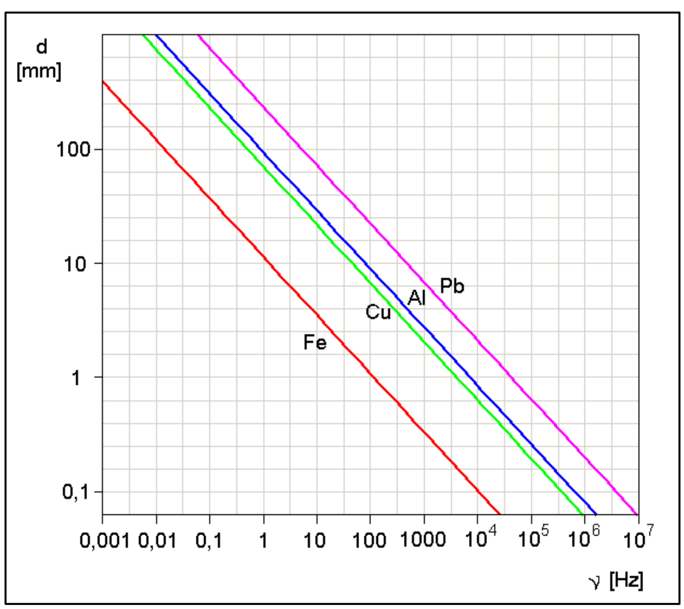

Figure 16. Skin depth versus frequency for various metals.

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5. Numberger, M. W.; Abdelmoneum, M. A.; Volakis, J. L. New Techniques for Extremely Broadband Planar Slot Spiral Antennas. Antennas and Propagation Society International Symposium, IEEE **July 1999**, *4*, 2690–2693.

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